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ECONOMIC AND HEALTH PERSPECTIVES OF MYCOTOXINS: A REVIEW.

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ABSTRACT
Due to their potent toxicity, mycotoxins have attracted worldwide attention over the years and recently, there has been an increasing disquietness on the part of governments, producers, processors, marketers and consumers over the health and economic significance. The diversity in occurrence, structure and chemistry of mycotoxins make their impact more complex to diagnose. Owing to their usual environmental conditions of production in countries with warm and humid climates as well as poor conditions of storage and handling, agricultural commodities are susceptible to fungal colonization and development which can lead to the accumulation of mycotoxins. As part of drying process, agricultural produce are exposed to contamination by ubiquitous mycoflora that grow, develop and produce some toxic metabolites that are harmful to the consumers. Food is already a limited commodity, especially in developing countries of the world and consumers therefore, either as a matter of choice or for the relative cheapness and affordability during periods of scarcity, opt for the over-fresh produce, sometimes not aware of the adverse health implications such foods pose. In the quest to ensure regular and continuous availability of certain perishable farm produce, especially in developing nations, local farmers and traders resort to unscientific and faulty storage conditions to preserve commodities, thereby pre-disposing produce to fungal colonization and mycotoxin production. Thus, commodities such as groundnuts, maize, sorghum, rice, yam, cassava, tiger nut, soyabeans, cotton seeds, fruits, vegetables spices can be contaminated with toxins of fungal origin such as aflatoxins, ochratoxins, fumonisins, patulin, sterigmatocystin, deoxynivalenol, zearalenone and other mycotoxins which pose serious economic and health risks. This review presents some mycotoxins commonly found on agricultural commodities both in temperate and tropic regions of the world. The acute and chronic toxic effects of these toxins in humans and animals are highlighted. Control measures include education of the populace on the risks of exposure to mycotoxins through skin contact, inhalation and ingestion, early harvesting, rapid appropriate drying, sequestration of diseased seeds from sound seeds, sanitation, use of good agronomic practices, insect control, the use of botanicals and synthetics as storage protectants, biological control and detoxification of mycotoxin-contaminated commodities. Probable related health implications are also discussed with a view to creating better public awareness and providing scientific basis for appreciating the challenges, while proactively promoting the development and implementation of policies at mitigating risk factors. Some mycotoxins, their producer fungi and toxic effects are further presented.

KEYWORDS*:* mycotoxins, control, commodity, health, economy.

INTRODUCTION
Mycotoxins are low molecular weight, toxic compounds produced by certain strains of a variety of filamentous fungi; under appropriate conditions (such as moisture and temperature) and all over the world, they cause enormous economic losses annually to the grain trade and the marketing of foods and feeds (Windels, 2000). For instance, the estimated losses in wheat and barley attributed to the *Fusarium* mycotoxins in the United State alone are about 2,900 million US Dollars a year, while the financial losses caused by mycotoxins due to decreases in the productivity of farm animals are however difficult to assess (Windels, 2000; CAST, 2003). However, according to Cardwell *et al.* (2001), the estimated losses due to *Fusarium* toxins (deoxynivalenol (DON) and Zearalenone (ZEA) to Ontario pork producers alone was put at $\$9 \times 10^6$ as a result of reproductive problems arising from zearalence, while that due to DON (Vomitoxin) was put $\$12 \times 10^6$ as a result of reduced growth rate in growing and finishing hogs because the animals eat less feed when contaminated with DON. Contamination of grains by aflatoxins alone inflicts annual losses of more than $750 million in Africa and is a major economic and health problem for the continent (*Goyal et al*., 2003). Mycotoxins have attracted worldwide attention due to the significant losses associated with

their impact on human and animal health and consequent national economic implications (Bhat and Vashanti, 1999; Makun *et al*., 2009). Though mycotoxins have impacted mankind since the beginning of organized crop cultivation, their effects have largely been ignored until the past forty years. The scientific study of mycotoxin began in 1960, when a large number of turkey poults died in England due to consumption of contaminated ground nut meal imported from Brazil (Blount, *1961).* A toxigenic fungus identified as *Aspergillus flavus* was isolated from the groundnuts and the toxigenic principle was named aflatoxin, meaning *A. flavus* toxins. Over 300 mycotoxins have been reported (Jestoi *et al.*, 2004). However, based on extensive analytical studies (IARC, 1993; Bhat and Vashanti, 1999) and detailed study of the distribution of fungi in nature, the five agriculturally important toxins from fungi are aflatoxins, fumonisins, Ochratoxins, Zearalenone and deoxynivalenol. Over $100 billion of exported commodities all over the world are susceptible to mycotoxin contamination (Cardwell *et al*., 2001).

Mycotoxin contamination of commodities and the implications

These toxic substances are known to be either carcinogenic (aflatoxin B1, ochratoxin and fumonisin B1); oestrogenic (zearalenone), neurotoxic (fumonisin B1) nephrotoxic (ochratoxin) demartotoxic (trichothecenes); immunosuppressive (aflatoxin B1, ochratoxin A, T-2 toxin) (Bankole and Adebanjo, 2003; Jestoi *et al*., 2004; Coronel *et al*., 2010). The consumption of mycotoxin contaminated commodities is related to several acute and chronic diseases in human and animals (Bhat and Miller 2010) and the diseases or physiological abnormalities resulting from exposure to mycotoxins are known as "Mycotoxicosis".

Unlike the bacteria toxins that are macro-molecular proteins that produce symptoms in a few hours, because the body recognizes them as antigens and produces antibody-mediated reaction, mycotoxins are low molecular weight toxic metabolites of fungal origin, that when ingested, inhaled or absorbed through the skin cause lowered performance, sickeness or death in human and animals (Bankole, 2003; Diaz, 2000, Fapohunda, 2008).

Owing to their potent toxic nature and fairly common occurrence under natural conditions, mycotoxins have attracted worldwide attention in recent years. Some acute diseases with evidence of association with mycotoxins include aflatoxic hepatitis in Kenya (2004-2005) and India, enteric ergotism in India, varcular erogitsm in Ethiopia and deoxynivalenol mycotoxicosis in India and China (Alemu *et al.,* 2008*;* Bhat and Miller 2010) and the involvement of stable food (such as corn, wheat, millet etc) was a common feature in all these. According to Bhat and Miller (2010), among food contaminants, mycotoxins have greater consequences in terms of both human and animal health as well as economics. Epidemiological (Missmer *et al.*, 2006) and experimental (Gelineau-Van Waes *et al.*, 2009) evidences suggest that *Fumonisins* are potential neural tube defect risk factors in populations dependent upon maize as a diet staple. Examples of fungi that have toxigenic strains are *Aspergillus turbingensis* and *A. ruber* (Perrone *et al*., 2006), *Fusarium verticilioides, A. flavus* (Bankole and Joda, 2004 and Jestoi *et al*., 2004), *A. ochraceus* (O' Challagan *et al*., 2006), *A. parasiticus* and *A. nominus* (Hell *et al*., 2000). Consumption of mycotoxins has often resulted in serious health problems such as bleeding from the lungs, incoordination, changes in reproductive cycles and infertility (Annor *et al*., 2004).

Typically, according to Paul *et al*. (2001), the higher incidence of oesophageal cancer among the male population in Kwazulu natal, South Africa was attributed to the consumption of house made beer from moldy cobs that contain high levels of fumonisin. Also, fumonisin production by *Fusarium verticillioides* has been statistically associated with oesophageal cancer in humans in China, Italy, Iran and South Africa, (Rheeder *et al*., 1995; Paul *et al*., 2001)). Mycotoxins have been implicated as etiological factors in different human diseases as well as their ability to evoke feed refusal, reproductivity, poorer reproductive capacities or diminished resistance to infectious agents in animals (CAST, 2003). These toxins are harmful to humans and livestock and they enter subsequently into milk and milk-based foods (Makun *et al*., 2009). The main sources of mycotoxins in human and animal nutrition are usually grains and grain-based products and the presence of mycotoxins cannot be assessed on the basis of appearance of fungal growth (Petterson and Aberg, 2002; Danks *et al*., 2003; Coronel *et al*., 2010).

In general, mycotoxin and particularly aflatoxins seem to pose great problems in the tropics than in the temperate regions, but no part of the world can be considered to be mycotoxin-free zone due to the movement of various food stuffs from one part of the globe to the other (Whittaker *et al*., 2007). The fact that toxins may persist long after the vegetative growth has occurred, even after the death of the mould, makes the presence of certain fungi a potential risk for health (Bueno *et al*., 2001). These toxins are chemically and structurally very stable and diverse (Tothill *et al*., 2006) and most frequently, human exposure.to these naturally occurring toxins is estimated from the contamination levels of raw food stuff or agricultural raw materials which are the primary sources of toxin exposure and data on food consumption patterns (Shephard *et al,* 2006). Concerns regarding their high toxicity

resulted in the United States Food and Drug Administration (FDA) and the European Union (EU) to set regulatory limits on the permissible levels of aflatoxins and ochratoxins and guidelines issued for deoxynivalenol, fumonisins and patulin.

Mycotoxins pose a threat to human and animal health through the ingestion of or exposure to contaminated food or feed. The Food and Agricultural Organization (FAO) of the United Nations has estimated that 25% of the world food crops are contaminated by mycotoxins each year (Dahman-levinson *et al*., 2006) and cereals and derived foods are assumed to be the major dietary source of Ochratoxin which is produced by several species of *Aspergillus* and *Penicillium.*

According to Moss (2008); Esono *et al.* (2008) and Coronel *et al.*(2010), Ochratoxin A has been reported in other plant products (including coffee beans, cereals and derived products, pulses, dried fruits, wines beers, spices, nuts, olives, grapes, beans and figs). There is a risk to human health not only through the intake of contaminated food of vegetable origin, but also through foods of animal origin with ochratoxin A being reported in animal-derived food products such as poultry and pork and in offal and sausages containing pork blood, due to the feeding of mould contaminated fodder to animals (Visconti *et al*., 1991; Makun *et al*., 2009). In addition, ochratoxin A can survive many typical processing procedures and has been reported in bread made from contaminated wheat and in both bottled and draught beers (Gbodi *et al*., 2001). Also, Oluwafemi (2000) reported detectable amount of Ochratoxin A in processed cocoa beans and cocoa-based beverages meant for final products. Both processed and unprocessed samples contained at least 20µg/kg of Ochratoxin A and 3µg/kg being the European union regulatory limit for ochratoxin A in food samples. Aflatoxin B1 and fumonisin B1 have been associated with the etiology of oesophageal cancer in South Africa and it has been supported by immunolocalization of fumonisin B1 in oesophageal cancer tissues (Paul *et al*., 2001).

Some of these toxins are known to have mutagenic or teratogenic properties as well as reproductive and developmental toxicity. For these reasons, mycotoxins pose a health risk to both animals and humans (Gong *et al*., 2002; CAST, 2003; Coronel *et al., 2010*). Also, mycotoxins evoke large economic losses on a global scale for many commercial sectors such as food producers and food and feed processors as well as animal breeders (Sydenham *et al*., 1991; Jestoi *et al*., 2004). The total number of mycotoxins is not known but the number of potential toxic metabolites of fungal origin has been estimated to be in the thousands, although to date, only about three hundred different mycotoxins have been identified (CAST, 2003). It is difficult to estimate the number of mycotoxins that are involved in mycotoxicoses because of the diversity of their toxic effects (Gatti *et al*., 2003; Diaz, 2000). For instance fusaproliferin has been shown to have teratogenic effect on chicken embryos (Ritieni *et al*., 1997) and found to be toxic to brine shrimps (Logrieco *et al*., 2003; Fapohunda *et al*., 2008). The knowledge of the occurrence and distribution in foods and feeds is important because, exposure to these bioactive agents can be a vital confounding factor in attempts to explain the etiology of chronic diseases in animals and humans (CAST, 2003; Diaz and Smith, 2005). Mycotoxins may be considered to be immunologic, hematotoxic, hepatotoxic, mutagenic, carcinogenic, demonecrotic or they can induce toxicity in the reproductive systems (Betina, 1989; CAST, 2003) and the toxicities of different mycotoxins vary greatly due to their chemical diversity (Betina, 1989). Fungal invasion and mycotoxins contamination of agricultural products lead to losses in terms of quantity, market value, quality of food and feed production due to changes in colour, texture and taste (Mutegi *et al*., 2009; Kaminski and Wasowicz, 1991) and reduction of seed germination (Hell, 1994; Negedu *et al*., 2010), energy and nutritional value changes in terms of loss of carbohydrates, proteins, amino acids and vitamins and increases in fatty acids may also occur (Ominski *et al*., 1994; Negedu *et al*., 2009). Given their toxicity and widespread occurrence, an accurate assessment of mycotoxin is essential for a reliable evaluation of human exposure to these carcinogenic mycotoxins (Dall Asta *et al*., 2006). Many evidences of reaction between fumonisins and food constituents such as sugars and proteins during food processing have been reported (Seefelder *et al*., 2003). Very recently, studies showed the presence of bound fumonisins in heat processed corn foods such as corn flakes, tortilla chips and corn chips (Kim *et al*., 2003; Park *et al*., 2004). Hidden fumonisins should be considered as a food safety concern because bound mycotoxins cannot be detected by the conventional analysis. Moreover, the occurrence of such products (bound fumonisin or hydrolysed fumonisin) should be carefully assessed on account of their hydrolysis in the gastro-intestinal tract.

Maize and groundnut have been found to be excellent substrate for aflatoxin contamination, while fumonisin are widely distributed in maize. Other food products for which mycotoxin contamination has been reported include yam chips, tiger nuts, melon seeds and stored herbal plants (Efuntoye, 1999; Rosa, 2003; Mphande *et al., 2004;*

Bankole and Joda, 2004; Hell, 2009). However, the safety of food and feed for human and animal consumption should be of topmost priority with regard to the regulation of agricultural and food industries and more so that food commodities are the major items of international trade, especially in developing countries and in particular, African countries (Conway and Toenniessen, 2003).

Fungal toxins can cause acute or chronic intoxications depending on the animals, sex, breed and dosage (Coker, 1979). There is ample evidence that the inhabitants of sub-saharan Africa are experiencing heavy dietary exposure to food-borne mycotoxins particularly aflatoxin and fumonisins. According to the World Development Report of 1993 (Miller, 1996) and NMA (2008), diseases caused by mycotoxins lead to reduced life expectancy especially in developing countries.

In many developing parts of the globe, especially Africa, the need to eat outweighs other considerations such as food safety and as such, this has made food-borne intoxications to be a serious problem in many parts (Kenya, Ethiopia, Togo, Mali, South- Africa etc.). According to Miller (1996), 40% of the productivity lost to diseases in developing countries was due to diseases exacerbated by aflatoxins. Regrettably, many of the people in the region are not even aware of the effect of consuming mouldy products (Bankole and Adebanjo, 2003).

Aflatoxins

The fungi, *Aspergillus flavus, Aspergillus parasiticus, A. clavatus* and *A. nominus* produce aflatoxins. *A. flavus* is the most common producer (Bradburn *et al*., 1993). These fungi occur principally in the soil and decaying vegetation. The four major aflatoxins are Aflatoxin B1, B2, G1 and G2. Aflatoxins M1 and M2 are hydroxylated metabolites of aflatoxins B1 and B2 respectively in animals. Exposure to aflatoxin is widespread in Africa (Ayalen *et al*., 2006). In a study carried out in the Gambia, Guinea Conakry, Nigeria and Senegal, over 98% of subjects tested positive to aflatoxin markers (Wild, 1996; Glaston *et al*., 2000; Moss, 2008).

Aflatoxin is a very powerful hepatocarcinogen and naturally occurring mixtures of aflatoxins have been classified as a class 1 human carcinogen (IARC, 1993) and has been positively correlated with male infertility in humans (Uriah *et al*., 2001). In a recent study in China, Li *et al.*(2001) found that levels of aflatoxin B1, B2 and G1 were significantly higher in corn from the high incidence area of human heapatocellular carcinoma and the average daily intake of aflatoxin B1 from the high risk area was 184.1µg. Aflatoxin synergies other agents such an hepatitis B in the causation of liver cancer (Turner *et al*., 2000). Though, the etiology and pathogenesis of Kwashiokor still remain obscured, much high aflatoxins have been found in the blood, urine and liver of children with the disease than similar age-matched children (Hendrickse, 1982; Ramjee *et al*., 1992) and the presence of the toxin was established in the autopsy brain tissues of some Nigerian children (Oyelami *et al*., 1996). In the United States, the Food and Drug Administration, uses an action level of 20µg/kg as the maximum residue allowed in food for consumption except for milk (FAO, 1996). Over one hundred countries all over the world have guidelines or regulations which prescribe a maximum acceptable limits for aflatoxins in food and feeds and the limit prescribed vary from 0 to 50 ppb (µg/kg) in food and from 0 to 100 PPb (µg/kg) in feed (Agagi, 2005). The Protein Advisory Group of United Nations (PAGUN) has recommended in take maximum of 30 ppb of aflatoxin in foods rich in protein, where use of contaminated food cannot be avoided. Avantaggo *et al*. (2002) found that insect damage of maize is a good predictor of *Fusarium* myctotoxin contamination and can serve as early warning of fumonisin contamination. Insects carry the spores of *Fusarium* from plant surfaces to the interior of the stalk or kernels or create infection wounds due to the feeding of the larvae on stalk or kernel (Munkvold and Hellminch, 2000).

For over all sanitary precaution, the European Union has enacted in 1998, very servere aflatoxin tolerance standards of 2 µg/kg aflatoxin B1 and 4 µg/kg total aflatoxins for nuts and cereals for human consumption (CEC, 1998) and this has come into effect from January, 2001 (Dimanchie, 2001). Consumers in the developed world are well aware of the carcinogenic effect of aflatoxins and will thus stay away from a product that has aflatoxin beyond the acceptance level. Exports of agricultural products particularly groundnuts and other oilseeds from developing countries have dropped considerately in recent years resulting in major economic losses to producing countries as a result of this restrictions (Otzuki *et al.*, 2001; Bhat and Visconti, 1999). According to the worldbank estimate, the policy change by the European Union will reduce by 64%, imports of cereals, dried fruits, oil seeds and nuts from nine African countries namely Chad, Egypt, Gambia, Mali, Nigeria, Senegal, South Africa, Sudan and Zimbabwe and this will cost African countries about US $670 million in trade per year (Kellerhal, 2000). However, the new rule of the EU has been criticized as being too stringent. There is the need for mycotoxin surveillance because of its wide occourence in contaminated commodities. For instance,

Akano and Atanda (1990) found aflatoxin Bl concentrations in the range of 20-455 µg/kg in groundnut cake ('Kuli Kuli') purchased from market in Ibadan, Oyo State, Nigeria. Similarly Adebanjo and Idowu (1994) reported that most of the corn-groundnut snacks, ('donkwa') contained aflatoxins above 30 µg/kg immediately after preparation.

Yamego and Kassamba (1999) reported that seeds of groundnut from Burkina faso inoculated with *Aspergillus flavus* excreted all the four major aflatoxins (B1, B2, G1 and G2) which peaked at 170 µg/kg after six days. Also, aflatoxin was detected in 98% of samples of dried yam chips surveyed in Benin with levels ranging from 2.2 to 220 µg/kg and a mean value of 141 µg/kg (Bassa *et al*., 2001). Furthermore, in Ogun and Oyo States of Nigeria, aflatoxin B1 was detected in 22% of yam chips purchased from open market (Bankole *et al*., 2008) and the presence of aflatoxin in tiger nuts (*Cyperus esculenta*) at toxicologically unsafe levels (Adebajo, 1993).

A correlation was established between the incidence of *Aspergillus flavus* and aflatoxin contamination detected in 55% of tiger nuts with concentrations ranging from 10-20 µg/kg collected from different parts of Nigeria (Bankole *et al*., 1996). In addition, a recent survey showed that 27% of melon seed samples from farmer stores contained aflatoxin B2 with mean levels of 14 µg/kg in the forest and 11 µg/kg in the savannah of Nigeria (Bankole and Adebanjo, 2004). Rice, which is widely, consumed in the country has also been reported by various authors to favour aflatoxin production. A recent survey in United Kingdom shows that retail rice was contaminated with aflatoxin, though at toxicologically safe levels {FSA, 2002).

One issue that has received little attention is the high risk associated with occupational exposure to mycotoxin contaminated products. Ewuola and Egbunike (2010) cited Dvorakova (1976) that in Czecho-SIavakia, two chemical engineers who had worked on a method of sterilizing pea nut meal contaminated with *Aspergillus flavus* were reported to have died from pulmonary adenomatosis and also the death of two British biochemists who developed adenocarcinomas of the colon was attributed to their exposure to purified aflatoxins (Dieger, 1976).

Ochratoxin

Ochratoxin is a mycotoxin produced by different species of *Aspergillus* and *Penicillium*, though it was first isolated from *Aspergillus ochraceus* (Van der Merve *et al*; 1965; Danks *et al*., 2003). Ochratoxin is found as a natural contaminant in many food stuffs including cereals, dried fruits, cocoa, wine, poultry eggs and milk. Ochratoxin has been related to the Balkan Endemic Nephropathy (BEN) which is nephrotoxic, immunosuppressive, teratogenic, genotoxic and mutagenic (Coronel *et al*., 2010) and IARC has classified it in group 2B as possibly carcinogenic to human (IARC, 1993; Hussein *et al*., 2001). According to Bankole and Adebanjo (2003), it was concluded by the Committee on Toxicity (COT) of chemicals in food, consumer products and environment that ochratoxin is a genotoxic, carcinogenic and that levels in food be reduced to the lowest that can be technologically attained.

The Joint Expect Committee on Food Additives of the World Health Organization (WHO) and Food Agricultural Organization (FAO) set a provisional maximum intake of l00µg/kg body weight, while the Scientific Committee of Food of the European Union proposed that the maximum daily intake of ochratoxin should not exceed 5ng/kg body weight (WHO, 1996). SedmiKova *et al*. (2001) found that ochratoxin can increase the mutagenic ability of aflatoxin B1 in the case of the two simultaneously occurring in the same crop. This toxin has also been established to be a problem in cocoa beans exported from West Africa (CABI, 2001).

Fumonisins

Fumonisins are fungal secondary metabolites produced by *Fusarium* species (e.g. *Fusarium verticilloides*, *Fusarium globosum*, etc) and can adversely affect human and animal health (Gutema *et al.*, 2000; Visconti, 2000). Fumonisins discovered in South Africa in 1988 (Fotso *et al.*, 2002; Marasas, 1995) and produced by *F. verticillioides*, *F. proliferatum* and *F. sporotrichioides* are recently receiving increasing attention in scientific literature because they have been implicated in a number of animal diseases such as leucoencephalomalacia in horses, which involves a massive liquefaction of the cerebral hemisphere of the brain with neurological manifestation such as abnormal movement, aimless circling, lameness, etc (Marasas, 1995), pulmonary edema in pigs (porcine), liver cancer in rat and haemorrhage in the brain of rabbits (Marasas, 1995; Nikiema *et al*., 2004). It can cause hepatotoxicity and neurotoxicity in many animals (Howard *et al*., 2001). It has been shown by the United States Food and Drug Administration, that a high exposure to fumonisin B1 caused liver cancer and decreased life expectancy in female mice and also induced liver carcinoma in male rat but did not decrease

the life span, (NTP, 1999). Some correlation studies have suggested a link between the consumption of maize with high incidence of *F. verticillioides* and fumonisins with the high incidence of human oesophageal carcinoma in certain parts of South Africa and China (IPCS, 2000; Yoshizawa *et al.*, 1994). The toxin has been demonstrated to induce apoptosis in cultured human cells and in rat kidneys (Hussein *et al*., 2001; Li *et al*., 2000; Tollenson *et al*., 1996) and IARC (1993) evaluated the carcinogenicity of grains contaminated with *F. moniliforme*, containing fumonisins and fusaric acid and found them to be possible human carcinogens. So far, Switzerland has a provisional tolerance value of l µg/kg for fumonisin B1 and B2 in maize products (FAO, 1997) while the United States has proposed a guideline of tolerance level of 2 µg/kg total fumonisin in corn for human consumption (FDA, 2001).

Many developing countries would like to export crops to European and other countries to facilitate earning of hard currency however, the majority of these importing countries have imposed restrictions on mycotoxin content in produce at the port of entry (Reddy and Thirumala-Devi., 2006). They are often less than 5 µg/kg of produce. Therefore, it is imminent that developing countries should only export either mycotoxin-free or containing permissible levels of any mycotoxin.

Factors affecting the production of mycotoxins

Mycotoxigenic fungi belong to the *Fusarium, Alternaria, Aspergillus* and *Penicillium* genera (Logrieco *et al.*, 2003) and toxigenic fungi can be divided into two main groups (Mutegi *et al*.,2009). Field fungi like *Fusarium* and *Alternaria* contaminate grains before or during harvest. The storage fungi (e.g. *Penicillium* and *Aspergillus*) are capable of growing at lower water contents than the field fungi and they tend to contaminate the grains in silos and other storage places. It is known that aflatoxin production is favoured by prolonged end of season drought and associated elevated temperatures (Rachaputi *et al*., 2002).

Generally speaking, it is not possible to determine a single set of conditions or factors which are critical to the growth of fungi and mycotoxin production. Mycotoxins are produced by a diverse group of fungi that differ in their morphology, biochemistry and ecological nitches (CAST, 2003; O'challagan, 2006) and it is a characteristic of the biosynthesis of secondary metabolites, that the amount produced is influenced not only by the environmental and nutritional parameters at the time of production, but also frequently by the previous growth history and development of the fungi. This means that the same fungi can produce different mycotoxins under different environmental conditions (Moss, 1991b). According to Lacey (1986), the type and amount of mycotoxin produced is always determined by the fungi, substrate and environmental factors. The environmental factors affecting the mycotoxin production are of physical, chemical or biological origin (Jarvis, 1971; Van Osenbruggen and Petterson, 2002). However, these factors rarely impact in an independent manner (Aldrick, 2003; Abramson *et al*., 2002), thus their interactions are usually more important that would be expected from simple summations of the actions on their own (Moss, 1991b) .

In addition to the environmental factors listed above pH, ionizing radiation and other fungal metabolites have been identified as affecting mycotoxin production (Moss, 1991b; Horn, 2006). The two primary factors which influence the growth and mycotoxin production of fungi are temperature and moisture (Lacey 1986). According to Lipps and Deep (1991); Tagne *et al*.(2003) and Jarvis (1971), if other factors are equal, then the field fungi typically require a higher moisture content to be present in the substrate (22-25%) than the storage fungi (13-18%).

The timing of the humidity determines the risk for mycotoxin contamination. Rainfall at the time of anthesis sensitizes crops to *Fusarium*-infection and subsequent mycotoxin contamination (Langseth *et al*., 1996). The concentrations of a trichothecene mycotoxin and deoxynivalenol (DON) in Norwegian oats were affected by the annual weather. The highest amount detected was after warm and dry springs with heavy rainfalls at the time of the anthesis. Cold summers with moderate rainfalls, instead led to low concentration levels of DON (Langseth *et al*., 1995; Langseth *et al*., 1999). In Finland, cold and rainy summers have led to the presence of lower levels of DON than those occurring in warmer and partly dryer growing season (Yli Mattila *et al.*, 2004). The effect of the weather condition seems to be relevant also to the new emerging mycotoxins as high levels of beauvericin (BEA) and enniatins (ENNs) were detected in Finnish grain samples with low levels of trichpthecenes after a very cold and rainy growing season (Eskola *et al*., 2001; Logrieco *et al*., 2002).

Genetic differences with the strains may contribute to the mycotoxin production, as some species may lack the genes needed for the production of certain myctotoxins (Nicholson *et al*., 2003). Even the same strains isolated

from different substrates or at different seasons may differ in their toxigenicity (Ominski, 1994; Dobson, 2006). Therefore, the current view is that the metabolite profile of a strain is regarded as an important parameter in the systematic taxonomics of a fungus. A species may possess the genes and operating enzymes needed for the production of particular mycotoxins, but for unknown reasons they are not formed in substantial amounts under field conditions (Lanyseth *et al*., 1999). This fact may lead to the misidentification of the fungi.

Other micro-organisms may affect the mycotoxin production and the grain may therefore be contaminated by a number of mycotoxins (CAST, 2003). The competing microbes may enhance or hinder the formation of mycotoxins by changing the metabolism of the producing organisms, by competing for the substrates by changing the environmental conditions making them unfavourable for mycotoxin production or by producing inhibitorial compounds { Ritieni *et al*., 1997). Interactions with other micro-organisms can also be different under different environmental conditions (Marin *et al*., 1998; Carins *et al*., 2003)and according to Kim *et al*. (2003), oxidative stress induces mycotoxin biosynthesis.

In the field conditions, several additional factors may influence the production of mycotoxins. These may include agricultural practices like tillage and crop rotation (lipps and Deep, 1991), lodging (Langseth and Stabbetorp, 1996) fungicide used (Moss and Frank, 1985), plant variety (Golinski *et al*., 1996; Chelkowski *et al*., 2000; Kiecana *et al.*, 2002) and geographical differences (Langseth *et al*., 1995). Also, organic cultivation practices may pose a risk for increased mycotoxin production, (Edward, 2003). The knowledge and understanding of the factors that affect the mycotoxin production of fungi is crucial to the success of preventive actions to minimize the exposure of humans and animals to mycotoxins. Based on an awareness of the many factors which can affect mycotoxin production and also the hazard analysis and critical control point (HACCP), management system has been applied to prevent mycotoxins contaminating the food chain (Alldrick, 2003).

Control Measures

The ideal goal for controlling mycotoxins is to eliminate mycotoxins from the food chain, however, on a practical level this is not possible (most of the mycotoxin – producing moulds are naturally occurring in soil and air, it is therefore difficult to prevent their contact with agricultural commodities). But the factors that affect the growth of moulds and their toxin production can be controlled (JECFA, 2001).

The most important factors are high moisture content (20 to 25%), high relative humidity (70% and above), and warm temperature (20 to 30^{o}C) (Ma *et al.*, 2002; Langseth *et al.*, 1995). These factors enhance mould growth and toxin production. Insects and mites cause physical damage on the commodities thereby, pre-disposing them for mould invasion and mycotoxin production. Several approaches for the prevention of mycotoxins have been presented based on biological antagonism (e.g. Galvano *et al*., 2001), chemical inhibition (e.g. Fanelli *et al.*, 2003; Hope *et al*, 2003)and plant breeding to achieve more resistant cultivars (e.g Ma *et al*., 2002). Three broad categories of preventive measures have been attempted. They include: plant breeding, good agronomic practices and detoxification.

Physical decontamination

Physical methods used for removal or elimination of mycotoxins from contaminated commodities include; density segregation and floation, cleaning and washing, sieving, dehulling, hand picking and electronic sorting, irradiation, milling; thermal degradation, solvent extraction and adsorption (Diaz, 2000; Ma *et al*., 2002).

The segregation of commodities into various particles sizes and subsequent removal of the fractions that contained higher toxin concentration reduced the level of mycotoxin in the entire commodities (Desjardins *et al*., 2000). Higher toxin concentrations were found in fractions containing smaller particles and the removal of these particles reduced the levels of toxins. For instance the levels of deoxynivalenol and zearalenone were from 73% to 83% and from 67 to 79% respectively in barley, wheat and corn (Afolabi *et al*., 2006). Also, removing of the hall portion from barley grain and rye contaminated with deoxynivalenol and zearalonone resulted in a 40% to 100% reduction of deoxynivalenol and zearalenone respectively, with a concomitant loss of 13% to 19% loss of the grain materials. (Afolabi *et al*., 2006).

Simple washing procedures, using distilled water resulted in 65% to 69% reduction of DON (16 to 24 mg/kg) and 2% to 61% of zearalenone (0.9 to 1.6mg/kg) in contaminated barley and corn (Gbodi *et al*., 2001). Washing with sodium carbonate solution increased the removal of deoxynivalenol and zearalenone up to 74% and 87%

respectively. Washing might be a useful treatment to use prior to wet milling or ethanol fermentation, otherwise the cost of drying grains would be prohibitive (Afolabi *et al*., 2006).

Mould damaged and mycotoxin contaminated kernels exhibit different physical properties with respect to undamaged, therefore, they may be separated by density segregation in certain liquid or fractionation by specific gravity table (Desjardins *et al*., 2000). Density segregation and removal of kernels buoyant in water and saturated sodium chloride solution reduced deoxynivalenol and zearalenone in cereals up to 96% and 55% respectively (Charmley and Prelusky, 1994). Although, significant amounts of deoxynivalenol can be removed by cleaning and polishing, the toxin remains in wheat flour of levels ranging from 60% to 80% of original toxin levels from the starting wheat (Charmley and Prelusky, 1994).

Corn screenings or broken corn kernels usually contain fumonisin level about 10 folds higher than infact corn, therefore the separation of the screenings, based on size, has been suggested as a candidate method for decontamination (Gbodi *et al*., 2001; Desjardins *et al*., 2000).

Irradiation (y-irradiation, X-rays, ultraviolet light, visible light) has been used for inactivation or destruction of some mycotoxins. Gamma irradiation reduced T-2 toxin, zearalenone and deoxynivalenol levels of wheat, corn and soyabeans at 16%, 25% and 33% respectively and DON and fumonisin in corn of 13% and 20% respectively (Scott, 1996; Diaz, 2000; Fanelli *et al*., 2003). Detoxification of 70% to 90% of trichothecenes was observed in Austria in contaminated corn by applying ultrasonication without altering its original taste and appearance (Glaston *et al*., 2000).

Addition in the diet of nutritionally inert sorbent (hydrated sodium calcium aluminosilicates, zeolite activated carbon, bentonite, clays and special palymers) reduces the absorption of mycotoxins from the gastro intestinal tract, thereby, avoiding the toxic effects for livestock and their carryover into animal products (Siame *et al.*, 1998). The efficiency of the absorption depends on the chemical structure of both the adsorbent and the mycotoxin.

BIOLOGICAL DECONTAMINATION

Biological detoxification it involves the enzymatic degradation or transformation of toxins leading to less toxic products. A yeast fungus *Exophiala spinifera* was able to grow on fumonisin B1 and a sole carbon source. It hydrolyzed fumonisin B1 yielding free tricarballylic acid and aminopentol and the hydrolysis was followed by oxidative deamination of the resulting aminopentol (Duvick *et al*, 1998). Fumonisin esterase and deaminase enzymes were isolated from the *spinifera* and expressed in transgenic corn plants showing a complete metabolization of fumonizin B1 with release of carbon dioxide (Duvick *et al*, 1998; Jestoi et al., 2004). While yeast expressing mycotoxin-degrading enzymes may offer a natural way of providing these activities, transgenic plants are being proposed as an economic approach to reduce fumonisin contamination of corn (Diaz and Smith, 2005).

Fermentation of wort-containing zearalenone by *Saccharomyces cerevisiae* resulted in conversion of 69% of the toxin to beta-zearalenol, a metabolite with less activity than the parent compound (Leggot and Shephard, 2001). The only product of biological origin now on the market is mycofix plus, produced by Biomin in Austria, which is claimed to degrade mycotoxins in feeds by enzymatic activities. It is a feed additive that inactivates trichothecenes by enzymatic decomposition of the 12-13 epoxy ring, and zearalenone by enzymatic opening of the lactone ring (Diaz and Smith, 2005; Goyal, 2003; Shephard *et al*., 2006).

Chemical decontamination

Moist ozone and dry ozone were able to reduce deoxynivalenol concentration in contaminated corn up to 90% and 70% respectively (Rosa *et al*., 2003). Ammoniation treatment combined with heat and pressure was able to reduce fumonisin level by 79% in corn contaminated with 86mg/kg of fumonisin B1 (Park *et al.*, 2004). Deoxynivalenol level was reduced by 9% and 85% in corn when exposed to 100% ammonia for 1 hour and 18 hours respectively (Rosa *et al*., 2003). Ammonia hydroxide (3%) was able to reduce zearalenone by 64% in naturally contaminated corn (33.5mg/kg) after 16 hours of exposure (Charmley and Prelusky, 1994; Moss, 1991a, 1991b; Hope *et al*., 2003).

Detoxification

Detoxification of aflatoxins in food and feed has been attempted in the past. For instance, Senegal operates commercial facilities to detoxify peanut cake contaminated with aflatoxins by ammonia process (Bhat and Miller, 2010; Hope *et al*., 2003; Simpson *et al*., 2001). However, any detoxification procedure must be tested for safety and efficacy and these results in increased handling costs and also the detoxified products has been considered suitable only for animal feed purposes and not for human consumption (Cardwell *et al*., 2001).

Several countries have introduced legislation concerning mycotoxins. Most of these pertain to aflatoxins, ergot alkaloids, deoxynivalenol and ochratoxins. Although various legislative measures have yet to be harmonized among countries, the Codex Alimentarius Commission is making efforts to establish international guideline levels for mycotoxins. Mycotoxin control measures have been implemented for agro-commodities entering international trade or located in countries with centralized or large scale buying and distribution systems(Ngoko *et al.,* 2001; Bhat and Vashanti, 1999; O' Challagan *et al.,* 2006). But, in developing countries, food consumption or subsistence agriculture is practiced by as much as 70% of the population, thus, such measures would be difficult to implement (Bhat and Vashanti, 1999).

Control measures also include education of the populace on the dangers of mycotoin contaminated diet, early harvesting, rapid drying, sorting, sanitation use of improved storage structure, insect control, use of botanicals and synthetic chemicals, biological control, use of resistant varieties and detoxification of mycotoxin contaminated grains (Jennings *et al.,* 2000; Munkvold, 1999). Monitoring of human population groups for diseases attributable to mycotoxins have to be carried our throughout the world to ensure a supply of safe food which is free of naturally occurring contaminants (Bhat and Miller, 2010; Missmer *et al*., 2009).

Plaint Breeding

Cultivating varieties of crops that are resistant to infestation by certain mycotoxin-producing moulds will minimize the problem of mycotoxin contamination (Ma *et al.,* 2002). For instance, the problem of ergot contamination of cereals and millet has been successfully minimized by cultivating varieties of rye, wheat, pearl millet that are resistant to the disease (Langseth *et al*., 1995; Torres *et al.,* 2001; Simpson *et al*., 2002). However, there has been little success in providing resistant varieties of corn and peanuts to minimize aflatoxins.

Agronomic and good agricultural practices:

Other agronomic practices such as avoiding water stress, minimizing insect infestation and reducing inoculum potentials help to minimize mold contamination and mycotoxin production (Langseth *et al*., 1996). According to Lipps and Deep (1991), good agricultural practices at both pre-harvest and post-harvest such as appropriate drying techniques, maintaining proper storage facilities and avoiding exposure of grains or oilseeds to moisture during transport and marketing are all control measures to help minimize mycotoxin contamination through minimizing mould growth. Sequestrating contaminated, moldy, shriveled or insect infested seeds from sound seeds have usefully minimized aflatoxin contamination in peanuts (Krysinska *et al*., 2001).

Mycotoxins negatively impact on agriculture and associated industries in all parts of the globe therefore, effort should be made to reduce and ultimately eliminate the adverse effects of mycotoxin contamination on the profitability of agriculture and related industries as well as the safety of food and feed throughout the world. The financial and human investments in this endeavour would be returned in terms of better human and animal health as well as reduced economic losses.

REFERENCES

Abramson, D. (1991). Mycotoxins in Agriculture and Food Safety. K.K. Sinha and D. Bhatnager (Eds), Marcel Dekker, New York, Pp. 255-277.

Abramson, D., Mccallum, B., Smith, D. M. and Tekau Z, A. (2002). Moniliformin in barley inoculated with *Fusarium avenaceum*. *Food Additives and Contaminants*, 19(8):765-769.

Adebajo, L. O. and Idowu, A.A. (1994). Mycoflora and Aflatoxin in a West African Corn-groundnut based convenience food. *Mycopathologia*, 126: 21 – 26.

Adebajo, L. O. (1993). Survey of aflatoxin and Ochratoxin A in stored tubers of *Cyperus esculentus*. *Mycopathologia*, 124:41-46

Afolabi, C. G., Bandyophadhyay, R., Leslie, J. F. and Ekpo, E. J.A. (2006). Effect of sorting on incidence and occurrence of Fumonisins and *Fusarium verticilloides* on Maize from Nigeria. *J. Food Prot*. 69(8) 2019-2023

Agag, B.I. (2005). Mycotoxins in foods and feeds: 5-Trichothecences A T-2 Toxin. *Ass.Univ. Bull.Environ.Res*. 8(2): 107-124.

Akano, D.A. and Atanda, O.O. (1990). The present level of aflatoxin in Nigerian groundnut cake (“Kuli-Kuli”). *Letters in Applied Microbiology*, 10:187-189.

Alemu, T., Birhanu, G., Azerefgne, F. and Skinnes, H. (2008). Evidence for mycotoxin contamination of maize in Southern Ethiopia: the need for further multidisciplinary research. *Cereal Research Communications*, 36 Number supplement B

Alldrick, A.J. (2003). Reducing the risk of mycotoxin contamination through the application of HACCP and other quality management techniques. *Aspects of Applied Biology*, 68: 139-146.

Annor,G., Afoakwa, E.O. and Sakyi-Dawson, E. (2004). Mycotoxin contamination in fermented foods: The present situation in West Africa”. *The conference on food safety under extreme conditions*, Jaen, Spain. Sept., 2004. *http://works.bepress.com/georgeamponsahannor/1*

Avantaggio, G., Quaran, F., Desidero, E. and Visconti, A. (2002). Fumonisin contamination of maize hybrid visibly damaged by Sesame. *J. Sci. Food Agric*. 83:13-18.

Ayalen, A., Fehrmann, H., Lepschy J., Beck, R. and Abate, D. (2006). Natural occurrence of mycotoxins in staple cereals from Ethiopia. *Mycopathologia*. 162 (1): 57-63

Bankole, S. A., Eseigbe, D. A. and Enikuomehin, O. A (1996). Mycoflora and aflatoxin production in pigeon pea stored in jute bags and iron bins *Mycopathologia*. 132:156-160.

Bankole, S., Schollenberger, M and Drochner, W (2008). Mycotoxins in food systems in Sub-Saharan Africa : A review : *Mycotoxin Research*. 22 (3): 163-169

Bankole, S.A. and Adebanjo, A. (2003). Mycotoxins in foods in West Africa: Current situation and possibilities of controlling it. *African Journal of Biotechnology* , 2 (9): 254-263.

Bankole, S.A. and Adebanjo, A. (2003). Aflatoxin contamination of dried yam chips marketed in Nigerian. *Tropical Science*, 43:3-4.

Bankole, S.A. and Joda, A.O. (2004). Effect of lemon grass (*Cynbopogun citratus* Stapf.) Powder and essential oil on mould deterioration and aflatoxin contamination of melon seeds (C*olosynthis citrulus* L.) *African Journal of Biotechnology*, 3: 52-59.

Bankole, S.A., Ogunsanwo, B.M. and Mabekoje, O.O. (2004). Natural occurrence of moulds and aflatoxins in melon seeds from markets in Nigeria. *Food Chemical Toxicology*, 42: 1309-1324.

Bassa, S., Mestres, C., Hell, K., Vernia, P. and Cardwell, K. (2001). First Report of aflatoxin in dried yam chips in Benin. *Plant Dis*. 85:1052.

Betina, V. (1989). Bioactive molecules: Mycotoxins chemical, biological and environmental aspects. Elsevier Science Publishers, Amstertadam, The Netherlands. Vol 9: Pp. 320

Bhat , R.V. and Miller, J.D (2010). Mycotoxins and food supply. FAO Corporate Document Repository. Sourced: *http://www.fao.org/docrep/u3550t/u3550t0e.htm* 1/25/2010

Bhat, R.V. and Vashanti, S. (1999). Occurrence of aflatoxins and its economic impact on human nutrition and animal feed. The new regulation. *Agricultural Development* No. 23: 50-56.

Blout, W.P. (1961). Turkey "x" disease. *Journal of British Federation,* 9: 52-57.

Bradburn, N., Blunden, G., Coker, R.d.and Jewers, K. (1993). Aflatoxin contamination of maize *Trop. Sci*. 33:418 – 428.

Bueno, D.J., Siva, J.O. and Oliver, G. (2001). Mycoflora in commercial Pet foods. *Journal of Food Protection*. 64: 114-150.

Calo, L., Fornelli, F., Ramires, R., Nenna, S., Tursi, A., Caiaffa, M. F. and Macchia, L. (2004). Cytotoxic effects of the mycotoxin beauvericin to human cell lines of mycloid origin. *Pharmacological Research*, 49: 73-77

Cardwell K. F. (2001). Mycotoxin contamination of foods in Africa: Anti nutritional factors. *Food and nutrition Bulletin*, 21:488-492.

Cardwell, K.F., Desjardins ,S.H., Munkold, G. and Rubens, J. (2001). Mycotoxins: The cost of achieving food safety and food quality. APSnet Feature story. Ed. Elliot, M.L. August 2001. *http://www.apsnet.org/online/feature/mycotoxin/*

Carins, V., Hope, R. and Magan, N. (2003). Environmental factors and competing mycoflora affecting growth and ochratoxin production by *Penicillium verrucosum* on wheat grain. *Aspects of Applied Biology,* 68: 81-90.

Charmley, L. L. and D. B. Prelusky (1994). In: Mycotoxins in grains: compounds other than aflatoxins. J. D. Miller and H. I. Trenholm (eds), Egan Press, St. Paul, Minnesota, USA PP: 421-435.

Chelchowski, J., Kaptur, P., Tomkowiak, M., Kostecki, M., Golinski, P. and Bocianowski, J. (2000). Moniliformin accumulation in kernels of triticale accessions inoculated with *Fusarium avenaceum* in Poland. *Journal of Phytopathology*, 148: 433-439.

Coker, R.D. (1979). Aflatoxin: past, present and future. *Tropical science*, 21:143-162.

Commission of European Communities (CEC) (1998). Regulation (EC) No. 1525/98 of 16 July, 1998. *Official Journal of European Communities* L 20/143, 17 July.

Commonwealth Agriculture Bureau International (CABI) (2001). Mycotoxin (OTA) producing fungi in West African cocoa crops. Focal Point: OFP-CAB International: Association of chocolate biscuits and confectionary industries of EU. (Available online) www.wisard/shared/asp/pro.asp

Conway, G.M. and Toennienssen, D. (2003). Agriculture: *Science for African Food Security Association,* 299: 1187-1188.

Coronel, M.B.; Sanchis, V.; Ramos, A. J and Marins, S. (2010). Review. Ochratoxin : Presence in human plasma and intake estimation. *Food Sci. Tech.* 16 (1): 5-18.

Council for Agricultural Science and Technology (CAST) (2003). Ames, IOWA, U.S.A Mycotoxins. Risks in plants, animals and human systems. *Task Force Report,*139 January, 2003.

Dahmen-Levinson, U., Levinson, S. Mallwitz, F. and Abdallah, N. (2006). Fluorescence polarization - a rapid and reliable technique to quantity the Mycotoxin contamination study for zearalenoue (ZON). PP 104. *Book of Abstracts,* International Conference on "Advances on genomics, biodiversity and rapid systems for detection of toxigenic fungi and mycotooxins" September 26-29, 2006. Monopoli (Bari), Italy. P 37. Retrieved from http://www.Ispa.onr.n/mycoglobe-2006.

Dall' Asta, C., Galaverna, G., Sforza, S., Dossena, A. and Marchelli, R. (2006). A new LC/ESI/MS/MS Method for the quantification of natural and hidden fumonisin in corn and corn-baked products. *Book of Abstracts*, International Conference on "Advances on genomics, biodiversity and rapid systems for detection of toxigenic fungi and mycotooxins" September 26-29, 2006. Monopoli (Bari), Italy. P 37. Retrieved from http://www.Ispa.onr.n/mycoglobe- 2006

Danks, C., Ostoja-Starzewska, S., Flint, J. and Banks, J. N. (2003). The development of lateral Sflow device for the discrimination of OTA producing and non-producing fungi. *Aspects of Applied Biology,* 68: 21-28.

Desjardins, A. E., Manandhar, G.G., Plattner, R. D., Maragos, C. M., Shrestha, K. and McCormick, S. P. (2000). Occurrence of *Fusarium* species and mycotoxins in Nepalese maize and wheat and the effect of traditional processing methods on mycotoxin levels. J. Agricultural food Chem. 48:1377 – 1383.

Diaz, D. E. and Smith, T. K. (2005). Mycotoxin sequestering agents: Practical tools for the neutralization of mycotoxins in the mycotoxin Blue Book. D. Diaz, ed. Nottingham Univ. Press, Nottingham, U. K. Pp. 313-339

Diaz, D. E., Hopkins, B. A., Leonard, L. M. Hagler, W. M. and Whitlow, L. W. (2000). Effects of fumonisin on lactating dairy cattle. *J. Dairly Sci*. 83 (Abstract): 1171.

Dimanchie, P. (2001). Groundnut exporters in Southern countries penalized by new standards on aflatoxins imposed by the European Union. *Lipids,* 8: 237-238.

Dobson, A.D.W., Ortoneda, M. and O'challagan, J. (2006). Advances in ochratoxin A biosynthesis. *Book of Abstracts*, International Conference on "Advances on genomics, biodiversity and rapid systems for detection of toxigenic fungi and mycotooxins" September 26-29, 2006. Monopoli pp39 (Bari), Italy. Retrieved from http://www.Ispa.onr.n/mycoglobe-2006

Duvick, J., T. A. Rood, J. R. Maddox and J.Gilliam (1998). Advances in ochratoxin A biosynthesis. *Book of Abstracts*, International Conference on "Advances on genomics, biodiversity and rapid systems for detection of toxigenic fungi and mycotooxins" September 26-29, 2006. Monopoli (Bari), Italy Pp.39 Retrieved from http://www.Ispa.onr.n/mycoglobe-2006

Edwards, S. G. (2003). Fusarium mycotoxins in UK wheat. *Aspects of Applied Biology*. 68:35 – 42

Efuntoye M. O. (1999). Mycotoxins of fungal strains from stored herbal plants and mycotoxin content of Nigerian crude herbal drugs. *Mycopathologia* 147: 43 – 48 (pub. Med).

Eskola, M., Parikka, P. and Rizzo, A. (2001). Trichothecenes, Ochratoxin A and Zearalenone contamination and *Fusarium* infection in Finnish cereal samples in 1998. *Food Additives and Contaminants.* 18: 707-718.

Essono, G., Ayodele, M., Akoa, A., Foko, J., Filtenborg, O. and Olembo, S. (2008). Aflatoxin-producing Aspergillus spp. and aflatoxin levels in stored cassava chips as affected by processing practices *Food Control*, 20: 648-654

Ewuola, E. O. and Egbunike, G. N. (2010). Effects of dietary Fumonisin B1 on the onset of puberty , semen quality, fertility rates and testicular morphology in male rabbits. *Reproduction*, 139: 439-445.

Fanelli, C., Taddei, F., Jestoi, M. and Visconti, A. (2003). Use of resvertrol and BHA to control fungal growth and mycotoxin production in wheat and maize seeds. *Aspect of Applied Biology,* 68: 63-71.

Fapohunda, S. O., Ezekiel, C. N., Alabi, O. A., Omole, A. and Chioma, S. O. (2008). Aflatoxin-mediated sperm and blood cell abnormalities in mice fed with contaminated corn. *Mycobiology,* 36(4): 255-259

Food and Agriculture Organization (1979). Aflatoxin in Pistachio nuts

FAO, *Food and Nutrition Paper*: 13: 152-153. FAO of the United Nations, Rome.

Food and Agriculture Organization (FAO), (1996). Worldwide regulation for mycotoxins, 1995, FAO of the United Nations, *Food and Nutrition Paper*, 55. FAO, UN, Rome.

Food and Drug Administration (FDA) (2001). Food and Drug Administration (FDA) Guidance for Industry: Fumonisin levels in human foods and feeds. Available online www.cfsan.fda.gov/dms/fumonbg3.html); Washington, DC. Nov. 9, 2001.

Food Standard Agency (FSA) (2000).U.S Survey of retail rice for a range of mycotoxins. UK,Food survey information sheet No. 22/02, 36p.

Fotso, J., Leslie, J. F. and smith, J. S. (2002). Production of beauvericin, moniliformin, fusaproliferin and fumonisin B_1, B_2 and B_3 by fifteen ex-type strains of *Fusarium* species. *Applied and Environmental Microbiology*, 68(10): 5195 – 5197.

Galvano, F. A., Piva A., Ritieni, A and Galvano, G. (2001). Dietary strategies to counteract the effects of mycotoxins. A Review: *J. Food Prot*. 64:120-131.

Gatti, M.J., Fraga, M.E., Magnoli, C., Dalcero, C. and Rocha Rosa, C.A. (2003). Mycological survey for potential aflatoxin and ochratoxin producers and their toxicological properties in harvested Brazilian black pepper. *Food Additives and Contaminants,* 20: 1120-1126.

Gbodi, T.A., Makun, H.A., Kabiru, Y.A., Ogbadoyi, E., Tijani, S.A., Lawal, S.A. and Bayero, R.A. (2001). Effect of local processing methods on aflatoxin contents of some common Nigerian foods prepared from artificially contaminated maize, rice and sorghum. *Journal of Agricultural Science.* Mansoura University. 26: 3759 -3769.

Gelineau-Van Waes, J. B., Voss, K. A., Stevens, V. L., Speer M. C. and Riley, R. T. (2009). Chapter 5: Maternal fumonisin exposure as a risk factor for neural tube defects. *Adv. Food Nutr. Res*. 56:145-181.

Glaston, K. M., Mvula, M. A., Koaze, H. and Baba, N. (2000). Aflatoxin contamination of Kenyan maize flour and malted Kenyan and Malawian grains. *Sci Rep. Fac. Agric*. Okayama Univ. 89: 1-7

Golinski, P., Kostecki, M., Lasocka, I., Wisniewska, H., Chelkowski, J. and Kaczmarek, Z. (1996). oniliformin accumulation and other effects of *Fusarium avenaceum* (Fr.) on kernels of winter wheat cultivars. *Journal of Phytopathology*, 144: 495-499

Gong Y Y; Cardwell K F; Hounsa A; Egal S; Turner P C; Hall A J and Wild C P (2002). Dietary aflatoxin exposure and impaired growth in young children from Benin and Togo: a cross-sectional study. Brit Med. J. 325:20-21

Gong Y Y; Egal S; Hounsa A ; Turner P C; Hall A J; Cardwell K F and Wild C P (2003). Determinants of aflatoxin exposure in young children from Benin and Togo, West Africa; the critical role of weaning. Int J. Epidemiology. 32(4): 556-562

Goyal, R.K. (2003). Prevention and control of mycotoxins in food grains in India. Retrieved from http://www.fao.org/inpho/vlibrary/x0036e/x0036e17.htm on 10/17/2003.

Gutema, T., Munimbazi, C. and Bullerman, L. B. (2000). Occurrence of fumonisin and moniliformin in corn and corn-based products of U.S. Origin. *Journal of Food protection*. 63 (12): 1732 – 1737.

Hell, K., Cardwell, K. F. Setamou, M., Poehling, H. M. (2000). The influence of storage practices on aflatoxin contamination in maize in four agroecological zones of Benin, West Africa J. stored prod. Res. 36:365-382.

Hell, K.; Gnonlonfin,B.G.J.; Kodjogbe,G.; Lamboni,Y and Abdourhamane, I.K (2009). Mycoflora and occuuerence of aflatoxin in dried vegetables in Benin, Mali and Togo, West Africa. *International Journal of Food Microbiology*. 135 (2): 99-104.

Hendrickse, R. G., Coulter, J. B. , Lamplugh, S. M., Macfarlane, S. B., Williams, T. E. Omer, M. I. and Suliman, G. I., (1982). Aflatoxins and Kwashiokor: A study in Sudanese children. *Br. Med. J. (Clin. Res.)* 285 (6345): 843-846.

Hesseltine, C.W. (1976). Conditions leading to mycotoxin contamination of foods and feeds. In: Mycotoxins and other fungal related food problems (Edited by Rodricks, J.V.). Advances in Chemistry Series No. 149. *American Chemical Society*,Washington DC, USA. Pp 658-690

Hope, R., Jestoi, M. and Magan, N. (2003). Multitarget environmental approach for control of growth and toxin production by *Fusarium culmorum* using essential oils and antioxidants. In: Advances in Stored Product Protection (Eds) Credland, P., Armitage, D.M., Bell, C.H., Cogan, P.M. and Highley, E.), CABI Publishing, Wallingford, United Kingdom, pp. 96-108.

Horn, B.W. (2006). Biodiversity of *Aspergillus.* Section *flavi* in the USA. *Book of Abstracts*. Mycoglobe International conference. Monopoli (Bari) September 26-29, 2006. Italy. PP 47.

Howard, P. C., Epply, R.M., Stack, M.E., Warbrintton, A., Voss, K.A., Loretzen, R. J., Kovach, R.M.and Bucci, T.J. (2001). Fumonisin B1 carcinogenicity in a two year feeding study using F344 rats and B6c3F1 mice. *Environ.Health perspect.* 109: 277 – 282.

Hussein, H. S. and Brassel, J. M. (2001). Toxicity, Metabolism and impact of mycotoxins on humans and animals. Toxicology. 167: 101 – 134

International Agency for Research on Cancer (IARC) (1993). Some naturally occurring substances: food items and constituents, heterocyclic amines and mycotoxins. *IARC Monographs on Evaluation of Carcinogenic Risk to Humans*, Lyon, France, 56.

International Programe on Chemical Safety (IPCS) (2000). (International Programme on chemical safety) *Environment Health Criteria* 219 – Fumonisim B1 WHO, Geneva, 1 – 150.

Jarvis, B. (1971). Factors affecting the production of mycotoxins. *Journal of Applied Bacteriology,* 34: 199-213.

JECFA (2001). JECFA (2001) Joint FAO/WHO Expert Committee on Food Additives, Safety evaluation of certain mycotoxins in food. WHO *Food Additives Series* 47 and FAO Food and Nutrition Paper 74, Pp. 701.

Jennings, P. J. A. Turner and P. Nicholson (2000). Overview of Fasarium ear blight in the U.K. Effect of fungicide treatment on disease control and mycotoxin production In: Proceedings of the Brighton Crop Protection Conference: *Pests and Diseases*, 2000, Farnham, Uk. BCPC publications, 2:707 – 712.

Jestoi, M. (2004). Emerging *Fusarium* Mycotoxins in Finland. Ph. D. *Thesis*. Department of Applied Chemistry and Microbiology, University of Helsinki, Finland. PP. 122.

Jestoi, M., Rokka, M., Yli-Mattila, T., Parikka, P., Rizzo, A. and Peltonen, K. (2004). Presence and concentrations of the *Fusarium* - related mycotoxins beauvericin, enniatins and moniliformin in Finnish grains samples. *Food Additives and Contaminants,* 21: 794-802.

Kaminski, E. and Wasowictz, E. (1991). Mycotoxins: Fungi and quantity in drying and storage. J. Chelkowski (Ed.) Elsevier, Amsterdam, the Netherlands, Pp. 229-258.

Kellerhal, F.M (2000). *Climate and crop distribution*. In: Principles of field crop production, Sydney University Press, Sydney. Pp. 64-94.

Kiecana, I., Mielniczuk, E., Kaczmarek, Z., Kostecki, M. and Golinski, P. (2002). Scab response and moniliformin accumulation in kernels of oat genotypes inoculated with *Fusarium avenaceum* in Poland. *European Journal of Plant Pathology,* 108: 245 - 251.

Kim, E. K., Scott, P. M. and Lau, B. P. Y (2003). Hidden fumonisins in cornflakes. *Food Addit. Contam.* 20: 161-169.

Krysinska – Traczyk, W., Kiecana, I. Perkowski, J. and Dutriewicz J. (2001). Levels of fungi and myctoxins in samples of grain and grain dust collected on farms in Eastern Poland. *Annals of Agricultural and Environmental Medicine* 8: 269 – 274.

Lacey, T. (1986). Factors affecting mycotoxin production. In: Mycotoxins and phycotoxins edited by Steyn, P.S. and Vlegaar, R. 6th international IUPAC symposium on mycotoxins and phycotoxins, Pretoria, South Africa.

Langseth, W., Hqie, R. and Gullord, M. (1995). The influence of cultivars, location and climate on deoxynivalenol contamination in Norwegian oats (1985-1990). Acta Agriculture Scandinavica. Section B: *Soil and Plant Science*, 45: 63-67.

Langseth, W., Bernhorft, A., Rundberget, T., Kosiak, B. and Gareis, M. (1999). Mycotoxin production and cytoxicity of *Fusarium* strains isolated from Norwegian cereals. *Mycopathologia*, 144: 103-113.

Leggot N L and Shephard G (2001). Patulin in South African commercial apple products. *Food Control* 12 (2) 73-76

Li, F., Yoshizawa, T., Kawamura, O., Luo, X. and Li, Y. (2001). Aflatoxins and fumonisins in corn from the high incidence area for human hepatocellular carcinoma in Guangxi, China. J. Agric. *Food Chem.* 49: 4122-4126.

Li, Y. C., Ledoux, D. R., Bermudez, A. J., Fritsche, K. L. and Rottinghaus, G. E. (2000a). Effects of moniliformin on performance and immune function of boiler chicks. *Poultry Science* 79 : 26 – 32.

Li, Y. C., Ledoux, D. R., Bermudez, A. J., Fritsche, K. L. and Rottinghaus, G. E. (2000b). The individual and combined effects of fumonisin B1 and moniliformin on performance and selected immune parameters in turkey Poults. *Poultry Science* 79 : 871 – 878.

Lipps, P.E. and Deep, I.W. (1991). Influence of tillage and crop rotation on yield, stalk rot and recovery of fusarium and Trichodeama *spp.* from corn. *Plant Disease*. 75 : 828 – 833.

Logrieco, A. (1999). The effects of cereal substrate and temperature on production of beauvericin, moniliformin and fusaproliferin by *Fusarium subglutinans* ITEM- 1434. *Food Additives and Contaminants,* 16: 361-365.

Logrieco, A., Bottalico, A., Mulc, G., Movetti, A. and Perrone,G. (2003). Epidemiology of toxigenic fungi and their associated mycotoxins for some Mediterranean crops. *European Journal of Food Protection*, 109: 645 – 667

Logrieco, A., Rizzo, A., Ferracane and Ritieni, A. (2002). occurrence of beauvericin and enniatins in wheat affected by fusarium avenaceum head blight. *Applied and Environmental Microbiology*, 68 (1): 82 – 85.

Ma, H., Zhon, M., Liu, Z. and Liu, W. (2002). Progress on genetic improvement for resistance to wheat scab in KLA. *Journal of Applied Genetics,* 43: 259-266.

Makun, H., Gbodi, F. A., Akanya, O. H., Salako, A. E. and Ogbadu, G. H. (2009). Health implications of toxigenic fungi in two Nigerian staples: guinea corn and rice. *African J. Food Science*, 3(9) 250-256

Marasas, W.F.O. (1995). Fumonisins: Their implications for human and animal health. *Nat Toxins*, 3: 193 – 198.

Marin, S., Sanchis, V., Saenz, R., Ramos, A.T., Vinas, I. and Magan, N. (1998). Environmental factors *in vitro* interactions and niche overlap between *Fusarium moniliforme, F. proliferatum* and *F. graminearum, Penicillium* and *Aspergillus species* from maize grain. *Mycological Research,* 102: 831-837.

Miller J.D. (1996). Mycotoxins. In. Cardwell, K.F. (ed) *Proceedings of the workshop on mycotoxins in food in Africa*. November 6-10, 1995 at Cotonon, Benin International Institute for Tropical Agriculture, Benin. P. 18-22.

Missmer, S. A., Suarez, L., Falkner, M., Wang, E., Merrill, A. H. Jr., Rothman, K. J. and Hendricks, K. A. (2006). Exposure to fumonisins and the occurrence of neural tube defects along the Texas-Mexico border. *Environ. Health Perspect.* 114:237-241.

Moss, M. O. (2008). Fungi, quality and safety issues in fresh fruits and vegetables. *J. Appl. Microbiol.* 104(5) 1239-43

Moss, M.O. (1991a). Influence of agricultural biocides on mycotoxin formation in cereals. In: Cereal grain: *Mycotoxins and quality in drying and storage* (Eds) Chelkowski, J, Elsevier Science Publishers Amsterdam, The Netherlands.

Moss, M.O. (1991b). The environmental factors controlling mycotoxin formation. In : *Mycotoxin and animal foods* (Eds) Smith, J.E. and Henderson, R.S., CRC Press Inc., Boca Raton, Florida, USA. Pp 354-378.

Moss, M.O. and Frank, J.M. (1985). Influence of the fungicide tridemorph on T-2 toxin production by *Fusarium sporotrichioides. Transaction of the British Mycological Society,* 84: 585-590.

Mphande, F. A., Siame, B. A. and Taylor, J. (2004). Fungi aflatoxins and cyclopiazonic acid associated with peanuts retailing in Botswana. *J. Food Prot.* 67(1): 96-102

Mumkvold, G., Stahr, H. M., Logrieco, A., Moretti, A. and Rietieni, A. (1998). Occurrence of fusaproliferin and beauvericin in fusarium-contaminated livestock feed in Iowa. *Applied and Environmental Microbiology*. 64(10): 3923 – 3926.

Mutegi, C. K., Ngugi, H. K., Hendriks, S. L. and Jones, R. B. (2009). Prevalence and factors associated with aflatoxin contamination of peanuts from Western Kenya *International Journal of Food Microbiology*, 130, (1) 27-34

Muthoni, J. W., Njenga, L. N., Gathunbi, J. K. and Chemining, G. N. (2009). The occurrence of aflatoxins in maize and distribution of mycotoxin –producing fungi in Eastern Kenya. *Plant Pathology Journal,* 8(3):113-119.

National Toxicology Programe (NTP), (1999). Toxicology and carcinogenesis studies on fumonisin B1 in F344/N Rats and B6cF1 mice (feed studies). Technical Report Series 496: NIH Publication 99 – 3955; U.S. Department of Health and Human Services, National Institute of Health: Research Triangle Park, NC.

Negedu, A. (2009). Fungal deterioration of castor (*Ricinus communis* L.) seeds grown in Kogi state, Nigeria. Ph .D. *Thesis*, Ahmadu Bello University , Zaria pp. 290.

Negedu, A., Ameh J.B., Umoh, V.J and Atawodi, S.E. (2010). Occurrence of mycotoxins in *Aspergillus tamari*i-infected wild castor seeds in storage. *Continental Journal of Microbiology,* 4: 37-43.

Ngoko, Z., Marasas, W. F. O., Rheeder, J. P., Shephard, G. S., Wingfield, M. J. and Cardwell, K. F. (2001). Fungal infection and mycotoxin contamination of maize in the Humid forest and the western highlands of Cameroon Phytoparasitica 29(4)352-360

Nicholson, P., Chandler, E., Simpson, D. R., Thomsett, M. and Wilson, A. (2003). Molecular methods for species and chemotype detection of toxigenio fungi. *Aspects of Applied Biology* 68 : 11 – 20.

Nigeria Medical Association (NMA), (2008). Nigerian's life expectancy level drops to 42 years. *Daily Trust* Friday 25th January, 2008 Pg. 8.

Nikiema P N; Wornillow L; Traore A S; Wild C P and Turner P C (2004). Fumonisin contamination of maize in Burkina Faso, West Africa. *Food Addit. Contam.* 21 (9) 865-870

O'Challagan, J., Tapleton, P.C. and Dobson, A.D.W. (2006). Ochratoxin A biosynthetic genes in *Aspergillus ochraceus* are differentially regulated by pH and nutritional stimuli. *Fungal Genetics and Biology,* 43: 213-221.

Oluwafemi, F. (2000). Correlation between dietary aflatoxins and human male infertility. *Thesis*, University of Benin, Benin City Nigeria. PP 160.

Ominski, K.H. (1994). Ecological aspects of growth and toxin production by storage fungi. In: Miller, J.D., Trenholm, H.S. (Eds.). Mycotoxin in grains: Compounds other than aflatoxin. Eagan press, USA. Pp. 287-305.

Osenbrugen, W. A. and Petterson, H. (2002). Analysis of relevant Fusarium mycotoxins in cereals. The State of the art. Food safety of cereals. A chain wide approach to reduce *Fusarium* mycotoxins. 42 – 51 Wagingen.

Otzuki, T., Wilson, J.S. and Sewadeh, M. (2001). What price precaution? European harmonization of aflatoxin regulations and African groundnut exports. *European Review of Agricultural Economics,* 28: 263-283.

Oyelami, O. A., Maxwell, S.M., Adelusola, K .A., Aladekoma, T. A. and Oyelese, A.O. (1996). Aflatoxins in the autopsy brain tissues of children in Nigeria. *Mycopathologia* 132: 35-38.

Park, J. W., Scott, P. M., Lau, B. P. Y. and Levis, D. A. (2004). Analysis of heat processed corn foods for fumonisins and bound fumonisns. *Food Addit Contam.* 21:1168-1178.

Paul, K. C., Nceba, G., Michael, F. D. and Anil, A.C. (2001). Exposure of rural and urban population in Kwazulu Natal,South Africa to fumonisin B in maize. *Environmental Health Perspective,* 109: 253-260.

Perrone, G., Battilani, P., Pietri, A. and Logrieco, A. (2006). Ochratoxin A production and AFLP analysis of *Aspergillus carbonarius, Aspergillus turbingensis* and *Aspergillus niger* strains isolated from grapes in Italy. *Applied and Environmental Microbiology,* 72: 680-685.

Petterson, H. and Aberg, L. (2002). Rapid estimation of deoxynivalenol and *Fusarium* by near infrared spectroscopy. *Journal of Applied Genetics,* 43A. 141-144.

Ramjee, G., Berjak, P. Adhikari, M and Dutton M. F. (1992). Aflatoxins and kwashiorkor in Durban, South Africa. *Ann. Trop. Paediatr.* 12:241-247.

Reddy, D.V.R. and Thirumala-Devi, K. (2006). Safe to eat or why chickens die and human beings suffer from liver cancer: Towards development of cost-effective technologies for the estimation of mycotoxins in foods and feeds. Retrieved from *http://www.icrisat.org/gt-bt/Research Briefs/mycotoxin.htm* on 11/19/2006.

Rheeder, J. P., Sydenham, E. W., Marasas, W. F. O., Thiel, P. G., Shephard, G. S., Schlecter, M., Stockenstrom, S., Cronje, D. W. and Viljoen, J. H. (1995). Fungal infestation and mycotoxin contamination of South African commercial maize harvested in 1989 and 1990. *S. Afr. J. Sci.* 91:127-131

Ritieni, A., Monti, S. M., Randazzo, G., Logrieco, A., Moretti, A., Peluso, G., Ferracane, R. and Fogliano, V. (1997a) Teratogenic effects of fusaproliferin on chicken embryos. *Journal of Agriculture Food Chemistry,* 45: 3039-3043.

Ritieni, A., Moretti, A., Logrieco, A., Bottalico, A., Randazzo, G., Monti, S. M. Ferracane, R. and Fogliano, V. (1997b) Occurrence of fusaproliferin, fumonisin B1 and Beanvericin in maize from Italy. *Journal of Agricultural and Food Chemistry.* 45: 4011 – 4016.

Rosa, C.A. (2003). Mycological survey for potential aflatoxin and ochratoxin producers and their toxicological properties in harvested Brazilian black pepper. *Food Additives and Contaminants,* 20: 1120-1126.

Scott, P. M. (1996). Mycotoxins transmitted into beer from contaminated grains during brewing. *Journal of the Association of Official Analytical Chemists International,* 79:675.

Sedmikova, M., Reisnerora, H., Dufkova, Z., Burta, I. and Jilek, F. (2001). Potential hazard of simultaneous occurrence of aflatoxin B1 and ochratoxin A. *Veterinary. Medicine*, 46: 169-174.

Seefelder, W., Knecht, A. and Humff, H.U. (2003). Fumonisins and food constituents. *Journal of Agriculture and Food Chemistry,* 5: 5567-5573.

Shephard, G. S., L. Van der Westhuizen and V. Sewram (2006). Biomarkers of exposure to fumonisim mycotoxins. *Book of Abstracts*, International Conference on “Advances on genomics, biodiversity and rapid systems for detection of toxigenic fungi and mycotooxins” September 26-29, 2006. Monopoli (Bari), Italy. P 61.Retrieved from http://www.Ispa.onr.n/mycoglobe-2006

Siame, B. A., Mpuchane, S. F., Gashe, B. A., Alotey, A. and Teffera, G. (1998). Occurrence of aflatoxins, fumonisin B1 and zearalenone in foods and feeds in Botswana. *J. Food Prot.* 61:1670-1673

Simpson, D. R., G. E. Weston, J. A Turner, P. Jennings and P. Nicholson (2001). Differential control of head blight pathogen of wheat by fungicides and consequences for mycotoxin contamination. *European Journal of plant pathology* 107: 421 – 431.

Sydenham, E.W., Shephard, G.S., Thiel, P.G., Marasas, F.O.W. and Stockenstrom, S. (1991). Fumonisin contamination of commercial corn-based human food stuffs. *Journal of Agricultural Food Chemistry,* 39: 2014-2018

Tagne, A., Kongsdal, O., Ngoko, Z., The, C. and Mathur, S. B. (2003). Fusarium pallidoroseum in maize samples of three agro-ecological zones of Cameroon. *J. Stored Prod. Res.* 39, (4): 367-374

Tollenson, W.H., Dolley, K.L., Sheldon, W.C., Thurman, J.D., Bucci, T.J. and Howard, P.C. (1996). The Mycotoxin fumonisin induces apoptosis in cultured human cells and in livers and kidneys of rat. In Jackson L S *et al* (eds) Fumonisin in food; Advances in Experimental Medicine and Biology. Plenum press, New York, pp 237 – 250.

Torres, A, M., Reynoso, M. M., Rojo, F. G., Ramirez, M. L. and Chulze, S. N. (2001). *Fusarium* species (section liseola) and its mycotoxins in maize harvested in northern Argentina. *Food Additives and Contaminants* 18(9): 386 – 343.

Tothill, I.E., Heurich, M., Parker, C., Lanyon, Y.H. and Arrigan, D.W.M. (2006). Microsensors for mycotoxin detection in foods. PP 59. *Book of Abstracts*. Mycoglobe International conference. Monopdi (Bari) September 26-29, 2006. Italy. PP 47.

Turner, P.C., Mendy, M., White, H., Fortuin, M., Hall, A.J. and Wild, C.P. (2000). Hepatitis B infection and aflatoxin biomarker levels in Gambian children. *Trop. Med. Internal Health,* 5:837- 841.

Uriah, N., Ibeh, I.N. and Oluwafemi, F. (2001). A study of the impact of aflatoxin on human reproduction. *Afr. J. Reprod. Health*, 5:106 – 110.

Van der Merwe, K.J., Steyn, P.S., Fourie, L., Scoot, D.B. and Thero, I.J. (1965). Ochratoxin A, a toxic metabolite produced by *Aspergillus ochraceus* Wilh. *Nature*, 205:1112 – 1113

Visconti, A., Michelangelo, P. and Centonze, G. (2000). Determination of ochratoxin A in domestic and imported bears in Italy by immunoaffinity clean up and liquid chromatography. *Journal of chromatography,* 888:321-326

Visconti, A., Minervini, F., Lucivero, G. and Gambatesa, V. (1991). Cytotoxic and immunotoxic effects of fusarium mycotoxins using a rapid colorimetric bioassay. *Mycopathologia*. 113 – 181 - 186

Voss,,A.K., Riley,T.R., Snook, M.E and Gelieneau-Van Waes, J. (2009). Reproductive and sphigolipid metaboliceffects of fumonisin B1 and its alkaline hydrolysis products in LL/Bc Mice: Hydrolyzed fumonisin B1 did not cause neuraral tube defects. *Toxicological Sciences* 112 (2): 459-467

Whittaker, T. B., Doko, B. M., Maestroni, B., Slate, A .B. and Ogunbanwo, B. F. (2007). Evaluating the performance of sampling plans to detect fumonisin B1 in maize lots marketed in Nigeria. *J.A.O.A.C.* 90(4)1050-1059

Wild, C.P. (1996). Summary of data on aflatoxin exposure in West Africa. In: Cardwell KF (ed) proceedings of the workshop on mycotoxins in food in Africa. November 6-10, 1995 at Cotonou, Benin. *International Institute of Tropical Agriculture*, Benin P. 26.

Windels, C.E. (2000). Economic and Social impacts of *Fusarium* head blight: Changing farms and rural communities in the Northern great plains. *Phytopathology*, *90*: 17-21.

World Health Organization (WHO) (1996). Ochratoxin A –Toxicological evaluation of certain *Food Additive Series*. WHO, Geneva. Pp 363 – 376.

World Health Organization (WHO) (2000). Saving two in a billion, a case study to quantify the trade effect of European food safety standards on African Exports . (Available online) www/.worldbank.org/wbies/trade/newstandards.htm

Yameogo, R.T. and Kassamba, B .(1999). *Aspergillus flavus* and aflatoxin on tropical seeds used for snacks *Arachis hypogea*, *Balanites aegyptiaca* and *Sclerocarya birrea*. *Trop. Sci.* 39:46-49.

Yli-Mattila, T., Poavanen-huhtala, S., Parikka, P., Konstantinova, P., Gagkaeva, T., Eskola, M., Jestoi, M. and Rizzo, A. (2002). Occurrence of *Fusarium* fungi and their toxins in Finnish cereals in 1998 and 2000. *Journal of Applied Genetics*, 43A: 207-214.

Yoshizawa, T., Yamashita, A. and Luo, Y. (1994). fumonisin occurrence in corn from high and low-risk areas for human oesophageal cancer in China. *Appl. Environ. Microbiol*. 60:1626-1629.

List of important mycotoxins, producer fungi and principal toxic effects: (Goyal, 2003)

sMycotoxins	Producer fungi	Toxic effects
Aflatoxins	*Aspergillus flavus, A. oryzae, A. parasiticus A. nominus*	Potently carcinogenic, mutagenic and teratogenic
Ochratoxins	*A, ochraceus, A. flavus, Penicillium viridicatum, Penicillium verrucosum, A. niger, A. turbingensis*	Hepatotoxic, nephrotoxic,, teratogenic. Possible human carcinogen, immunotoxic and neurotoxic
Zearalenone	*Fusarium graminearum, F. tricinctuin, F. culmorum, F. crookweilense*	hyper-oestrogenic
Sterigmatocystin	*A. versicolor, A. nidulans, A. rugulosus*	Carcinogenic
Patulin	*P. patulum, P. expansum*	induces subcutaneous sarcoma
Rubratoxins	*P. rubrum, P. purpurogenum*	Haemorrhage
Citrin	*Penicillium citrinum, P. viridicatum*	Nephrotoxic
Citreoviridin (yellow rice toxin)	*Penicillium citreoviride*	nephrotoxic Producing convulsions
Penicillic acid	*Penicillium pulberulum*	cell necrosis
Trichothecenes (T-2)	*Fusarium poae, Fusarium roseum*	teratogenic, emetic, cytotoxic, animal and human carcinomas
Ergotoxins	*Clavicep purpurea*	abortive, gangrene development
Fumonisins	*Fusarium moniliforme, F verticillioides, Fusarium proliferatum, Fusarium poae*	carcinogenic, pulmonary oedema in pigs, leucoencephalomalacia in horses, hepatotoxic and carcinogenic to rats
fusaproliferin	*Fusarium avenaceum*	teratogenic to chicken embryos and toxic to brine shrimps
Malfonnins	*A. niger*	otomycosis, death, calcium depletion and haemorrhage,
Altertoxin	*Alternaria alternata*	Mutagenicity

European Economic Community (EEC) tolerance limit for aflatoxin B1 in animal feed (Goyal, 2003)

Commodity	Aflatoxin B1 tolerance not more than µg/kg or ppb
Produce for processing into mixed feed	50
Complete feed for cattle, sheep and goats (with exception of dairy animals, calves and lambs)	50
Complete feed for pigs and poultry with the exception of infant pigs, chicks, duckings and turkeys).	20
Animal feed supplements for dairy animals	20
Other complete feed	10

Aflatoxin limits in different countries (Goyal, 2003)

	Country	Commodity	Aflatoxin limit Hg/kgorppb)
1	Belgium	Animal feed	40***
2.	Brazil	Ground oil seed cake (export)	50
3.	Canada	Nuts and their derived products	15**
4.	Denmark	Groundnuts and brazil nuts	5-10
5.	France	Animal feed	700
6.	India	Groundnut kernel	30
7.	Israel	All foods	20
8.	Italy	Groundnuts	50***
9.	Japan	All foods	10
10.	Malaysia	All foods	0
11.	Walavi	Groundnuts	5
12	Netherlands	Foods and feeds	5
13.	Norway	Oil seed cake	600
14.	Poland	All food and feeds	5
15.	Rhodesia	Groundnuts	25
16.	Sweden	All food particularly	50-400
17.	United Kingdom	Confectionery, groundnuts, groundnuts flour for animal feeds	0-500*
18.	U.S.A	Confectionery,groundnuts All foods and animals feeds	20* 20-25

*Aflatoxin
Total of aflatoxin Bl, B2, Gl, G2. ***EEC limits may apply.

Physical, chemical and biological factors which can influence the mycotoxin production of fungi on crops at the different stages of food chain (Hesseltine, 1976).

Factor	Infield	At harvest	In storage
Physical			
Moisture	+	+	+
Rapidity of drying	-	+	+
Rewetting	-	+	+
Relative humidity	-	+	+
temperature	+	+	+
mechanical damage	+	+	+
blending of grains	-	+	+
hot spots	-	+	+
time	+	+	+
CHEMICAL			
carbon dioxide	-	-	+
Oxygen	-	-	+
nature of substrate	+	-	+
mineral nutrition	+	-	+
chemical treatment	-	-	+
BIOLOGICAL			
plant stress	+	-	+
invertebrate vectors	+	-	+
fungal infection	+	-	+
plant varietals differences	+	-	+
fungal strain differences	+	-	+
spore load	+	+	+
microbiological ecosystem	+	-	+

+ = site of effect
- = no effect.

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